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Cortical thickness and volume alterations in patients with high myopia: a magnetic resonance imaging study

Emre Aydin^{1*} and Ozgur Palanci^{2,3}

Abstract

Background The retina and optic nerve are integral components of the visual system and maintain direct anatomical and functional connections with the brain. Both structures are markedly affected in high myopia (HM). Accordingly, characterizing brain structural alterations associated with HM may provide important insights into its underlying neurobiological mechanisms. Using brain magnetic resonance imaging (MRI), this study aimed to evaluate regional gray matter (GM) and white matter (WM) volume changes, their relative percentages, and cortical thickness alterations in individuals with HM.

Methods High-resolution structural MRI, together with visual acuity (VA), intraocular pressure (IOP), refractive error, axial length (AL), and anterior chamber depth (ACD), was used to compare 30 adults with HM and 22 healthy controls (HC). Regional brain volumes and cortical thickness were analyzed in the fusiform gyrus (FuG), inferior temporal gyrus (ITG), middle temporal gyrus (MTG), superior temporal gyrus (STG), and occipital subregions including the calcarine cortex (Calc), cuneus (Cun), lingual gyrus (LiG), inferior occipital gyrus (IOG), middle occipital gyrus (MOG), and superior occipital gyrus (SOG).

Results Compared with HCs, HM patients demonstrated significant volumetric increases in the ITG and MTG regions (all $p < 0.05$), with the left ITG remaining significant after false discovery rate (FDR) correction. No significant volumetric differences were observed in the fusiform or occipital regions. In contrast, cortical thickness analyses revealed significant thinning in the fusiform gyrus and bilateral occipital subregions, including the calcarine cortex, cuneus, lingual gyrus, and middle occipital gyrus ($p = 0.000$ – 0.026 , FDR-corrected). Cortical thickness in the fusiform and occipital regions showed negative correlations with AL and ACD and positive correlations with spherical equivalent.

Conclusions High myopia is associated with region-specific brain structural alterations, characterized by volumetric increases in temporal regions and cortical thinning in fusiform and occipital areas, indicating that HM-related neuroanatomical changes extend beyond the ocular system to involve central nervous system structures.

Trial registration Not applicable.

Keywords High myopia, Brain morphology, Magnetic resonance imaging, Visual cortex, Axial length

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Background

High myopia (HM) represents a major global public health concern and is projected to affect approximately five billion individuals by the year 2050 [1]. Clinically, HM is defined as a refractive error exceeding -6.00 diopters (D) or an axial length (AL) greater than 26 mm. The condition, also referred to as pathological or degenerative myopia, is characterized by progressive and irreversible structural alterations in the neurosensory retina and choroid, which may extend to higher-order visual processing regions within the brain [2, 3]. The etiology of HM is multifactorial, involving complex interactions between genetic predisposition and environmental factors such as prolonged near work, limited outdoor activity, insufficient sleep, and higher educational attainment [4]. Importantly, HM predisposes affected individuals to a range of sight-threatening complications, including myopic choroidal neovascularization, retinal detachment, glaucoma, and cataract formation [5].

HM extends beyond being a purely ocular condition; accumulating evidence indicates that it exerts significant effects on the central nervous system. The retina and optic nerve, which are among the most severely affected structures in HM, are integral components of the visual pathway and maintain direct structural and functional connectivity with the brain [6]. Recent studies have revealed that, even in the absence of reduced best-corrected visual acuity (BCVA), individuals with HM exhibit alterations in visual function compared with emmetropic subjects. Therefore, characterizing the brain structural changes associated with HM may provide important insights into the neurobiological mechanisms underlying its pathophysiology. Several neuroimaging investigations have identified abnormalities in total brain volume, as well as in white matter (WM) and gray matter (GM) integrity, in patients with HM [7, 8].

Visual processing begins in the photoreceptors of the retina, where light stimuli are converted into electrical signals that are subsequently transmitted through the optic nerve, optic chiasm, and lateral geniculate nucleus to the occipital cortex [9].

Conventional magnetic resonance imaging (MRI) provides high-spatial-resolution anatomical images primarily based on contrast generated by tissue relaxation parameters, namely T1 and T2 [10]. In recent years, MRI-based structural brain analyses have increasingly been employed to investigate the effects of ocular disorders, such as HM, on the central nervous system. However, the majority of existing neuroimaging studies in HM have focused on global brain metrics or restricted regions of interest, and the reported findings remain inconsistent across studies. In particular, data addressing region-specific GM and WM volumetric alterations and detailed cortical morphometric features in HM are still

limited, hindering a comprehensive understanding of the central neuroanatomical correlates of this condition [11]. In this context, the application of automated, atlas-based segmentation approaches enables a more robust and standardized evaluation of regional brain morphometry.

To the best of our knowledge, the present study is among the first to simultaneously assess regional cortical thickness, absolute and percentage-based GM and WM volume changes in patients with HM using the volBrain platform. Unlike previous studies that examined isolated structural parameters, we adopted a comprehensive and standardized atlas-based morphometric approach to better characterize the structural brain alterations associated with HM.

Accordingly, the aim of this study was to evaluate regional GM and WM volume alterations, their relative percentage distributions, and cortical thickness patterns in patients with HM using brain MRI data, and to explore the potential associations between these morphometric findings and ocular biometric indices.

Methods

Participants

This study included 30 HM patients and 22 healthy control (HC) subjects. Differences between groups regarding age and gender were statistically analyzed. This observational and comparative study adhered to the principles of the Declaration of Helsinki and was approved by the Samsun University Non-Interventional Clinical Research Ethics Committee (Approval No. 2024/20/9). Written and verbal information about the study was provided to all participants, and written informed consent was obtained prior to their inclusion.

To exclude potential neurological disorders (including cerebral hemorrhage, stroke, psychiatric conditions, and other systemic diseases), all participants underwent a thorough medical examination and detailed anamnesis. Distance visual acuity (VA) was measured using a computerized LogMAR chart (Topcon ACP-8, Tokyo, Japan). Intraocular pressure (IOP) was monitored using a tonometer (Topcon CT-1P, Tokyo, Japan) and refractive errors were assessed without cycloplegia using an autorefractometer (Nidek ARK-510 A, Gamagori, Japan). Axial length (AL) and anterior chamber depth (ACD) were measured via ocular biometry (Argos, Alcon Inc., Fort Worth, TX, USA).

Inclusion criteria for the HM group were as follows: (1) Age over 18 years; (2) BCVA ≥ 1.0 ; binocular refractive error less than -6.00 D; and AL greater than 26 mm; (3) Absence of retinal degeneration, glaucoma, cataract, strabismus, amblyopia, or other ophthalmologic disorders; (4) No history of ocular surgery or long-term topical medication; (5) Informed consent for MRI, biometric, and ophthalmic examinations. Exclusion criteria

included: (1) Super HM (Although the definition of super high myopia varies across the literature, in this study, super high myopia (SHM) was defined as a spherical equivalent refractive error ≤ -10.00 D) [12] or monocular HM; (2) Coexisting ocular diseases such as glaucoma, cataract, uveitis, retinal detachment, amblyopia, or strabismus; (3) Fundus abnormalities associated with HM (e.g., macular hemorrhage, subretinal neovascularization, leopard pattern fundus, Fuchs spot); (4) History of ocular surgery or trauma; (5) Inability to cooperate adequately during ophthalmic examinations [13]. The HC group consisted of individuals with refractive errors between -0.75 D and $+0.75$ D and no ocular or systemic diseases.

Participant preparation

Prior to scanning, participants were instructed to remain awake with eyes closed while lying supine and maintaining a state of non-directed mentation. Symmetrical foam pads were placed bilaterally to minimize head movement, and earplugs were provided to reduce external noise. Wakefulness was continuously monitored throughout the procedure using a sleep monitoring device.

MRI protocol

All brain imaging procedures were performed using a 1.5 Tesla (1.5T) MRI system. A high-resolution T1-weighted MPRAGE (Magnetization Prepared Rapid Gradient Echo) sequence was applied. The typical imaging parameters were as follows: repetition time (TR) = 2300 ms, echo time (TE) = 2.98 ms, flip angle = 9° , slice thickness = 1 mm, and matrix size = 256×256 .

Image processing and volumetric analysis

T1-weighted brain images were processed using the vol2Brain module of the volBrain platform (<https://volbrain.upv.es>) [14]. Vol2Brain employs artificial-intelligence-based automated segmentation algorithms to compute total brain volume (GM + WM), cortical surface thickness, and regional brain volumes with high accuracy. In this study, particular attention was given to the fusiform gyrus (FuG), inferior temporal gyrus (ITG), middle temporal gyrus (MTG), superior temporal gyrus (STG), and subregions of the occipital lobe, including the calcarine cortex (Calc), cuneus (Cun), lingual gyrus (LiG), inferior occipital gyrus (IOG), middle occipital gyrus (MOG), and superior occipital gyrus (SOG). For each structure, volumetric measurements were obtained both as absolute values (cm^3) and as percentages normalized to total brain volume. For cortical regions, normalized cortical thickness values provided by vol2Brain were used in the statistical analyses. All processed images were reviewed using the individual reports generated by vol2Brain, and segmentation accuracy was visually inspected (Fig. 1). Segmentation outputs were assessed for gross mislabeling, inaccurate GM and WM boundaries, and incomplete cortical or subcortical delineation. No datasets were excluded following the segmentation quality control procedure.

Three-dimensional visualization

Three dimensional anatomical visualization was performed using the `mni_T1_jop.nii.gz` and `mni_structures_jop.nii.gz` files generated by the vol2Brain module. These files were imported into the 3D Slicer software

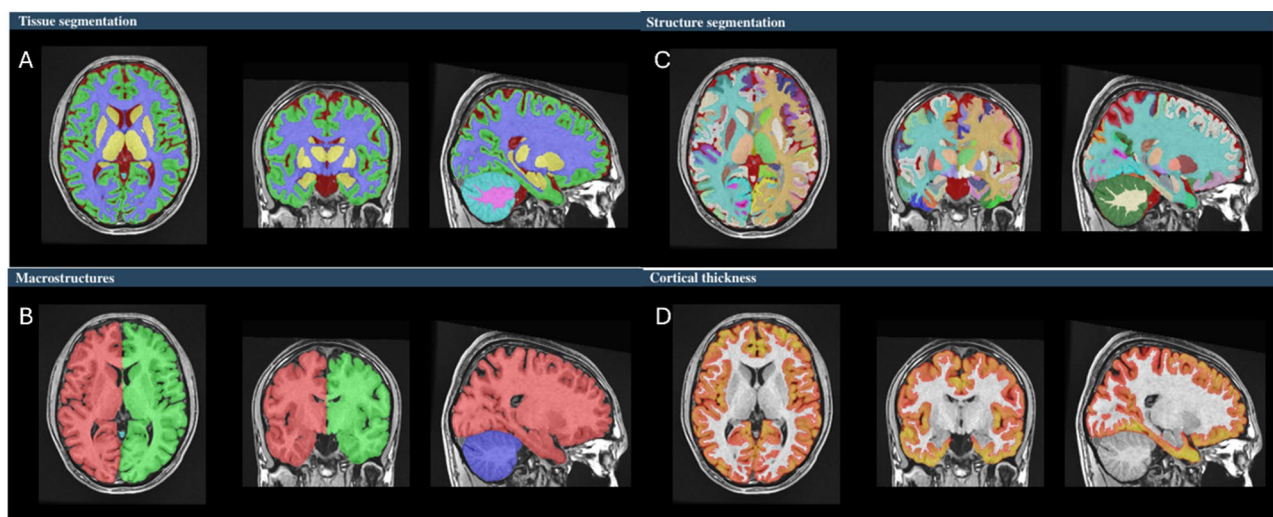


Fig. 1 Example images of segmentation outputs automatically generated by the Vol2Brain platform. The images were taken from the Vol2Brain automatic analysis report and belong to our own dataset. All segmentation maps were derived from the volBrain standard atlas. Segmentation accuracy was verified through visual inspection. **(A)** Tissue segmentation: gray matter, white matter, and cerebrospinal fluid regions, **(B)** Macrostructural segmentation: differentiation of the left and right hemispheres and the cerebellum, **(C)** Structural segmentation: various cortical and subcortical anatomical regions, **(D)** Cortical thickness maps: thickness variations across the cortex are shown with different color scales

(version 5.8.1; www.slicer.org) as “volume” and “segmentation” data. Within the 3D Slicer environment, the vol2Brain segmentation outputs were spatially aligned in volumetric format, and each structure was color coded to facilitate anatomical distinction. The spatial relationships among brain regions were then visualized in three dimensions (Fig. 2). In addition, surface smoothness, opacity, and lighting parameters were optimized to preserve the spatial integrity and realistic representation of anatomical structures [15].

Statistical analysis

To determine whether there were statistically significant differences in cortical thickness between the myopia patients and healthy control groups, normality assumptions were first evaluated. The Shapiro-Wilk test was used to assess normality. Variables with $p > 0.05$ were considered normally distributed and analyzed using the parametric Independent Samples T-Test. For variables with $p < 0.05$, indicating non-normal distribution, the non-parametric Mann-Whitney U Test was applied to compare group differences. For both Diagnosis 0 and Diagnosis 1 groups, the means, standard deviations, Cohen's d effect sizes, p-values, and false discovery rate (FDR) adjusted p-values using the Benjamini–Hochberg procedure to control for multiple comparisons are reported in the table. All analyses were performed with a power of 95% CI. A p-value < 0.05 was considered statistically significant.

Results

There were no statistically significant differences between the patient and control groups in terms of age and gender ($p > 0.05$). Brain volume percentages were compared

between the two groups in this study. The results demonstrated significant volumetric increases in the ITG and MTG regions of HM patients (right ITG $p = 0.012$, left ITG $p = 0.001$; right MTG $p = 0.020$, left MTG $p = 0.005$). Notably, the difference in the left ITG region remained significant after FDR correction ($p = 0.029$). No statistically significant differences were observed between groups in other brain regions such as the FuG, STG, and occipital subregions (Table 1). These findings indicate volumetric increased in the temporal lobe, particularly in the ITG and MTG regions, among HM patients.

Correlation analyses between brain volume measurements and ocular parameters revealed significant associations with the left ITG volume. A strong negative correlation was observed between left ITG volume and right eye spherical equivalent values ($r = -0.404$, $p = 0.003$). Additionally, positive and significant correlations were found between left ITG volume and right eye axial length (AL-R) ($r = 0.377$, $p = 0.006$) and anterior chamber depth (ACD-R) ($r = 0.347$, $p = 0.012$). Similarly, negative correlations between left ITG volume and left eye spherical equivalent ($r = -0.405$, $p = 0.003$), as well as positive correlations with left eye axial length (AL-L) and anterior chamber depth (ACD-L) ($r = 0.388$, $p = 0.004$ and $r = 0.372$, $p = 0.007$, respectively) were identified. No significant correlations were found with other ocular parameters (Table 2). These results suggested that left ITG volume is specifically associated with spherical equivalent and axial ocular measurements.

Cortical thickness analyses of various brain regions in myopic patients revealed significant reductions in the FuG of the left hemisphere and bilateral occipital lobes. These cortical thinning effects were significant in the occipital, Cal, Cun, LiG, MOG, SOG, and FuG regions

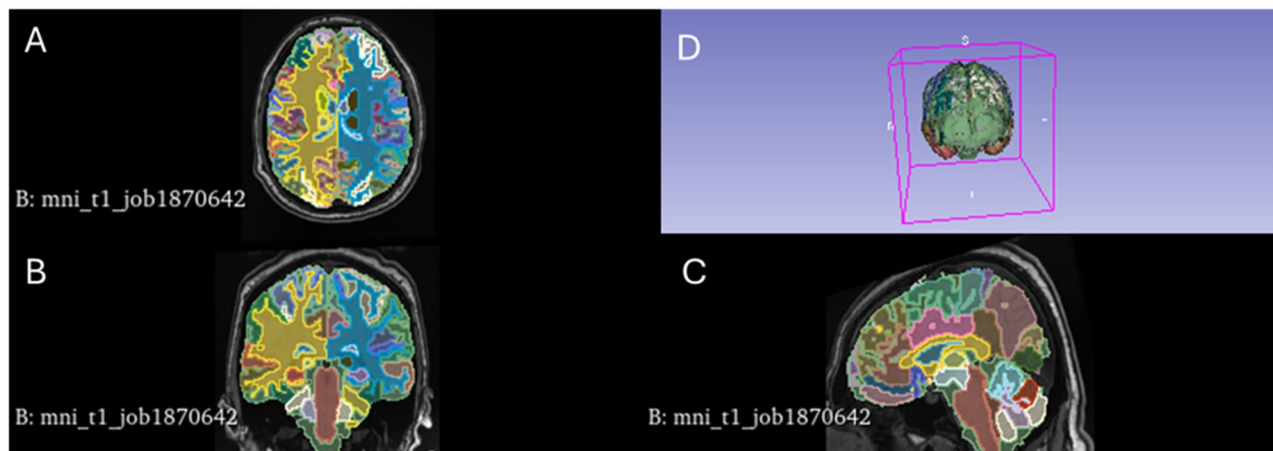


Fig. 2 Three-dimensional anatomical visualization of the files mni_T1_jop.nii.gz and mni_structures_jop.nii.gz generated by the Vol2Brain module using the 3D Slicer software. (A) Axial, (B) coronal, and (C) sagittal planes showing segmentation views with color-coded brain structures. (D) Three-dimensional volumetric reconstruction of the brain and three-dimensional presentation of the segmentation results. Each brain region is displayed in a different color to facilitate anatomical differentiation. Surface smoothness, opacity, and lighting parameters were optimized to preserve the spatial integrity and realistic representation of the structures

Table 1 Comparison of brain region volumes across diagnostic groups

Brain region volume	Myopia (n:30)	Healthy Control (n:22)	Cohen's d	p	FDR_p
	Mean $\pm$ Sd	Mean $\pm$ Sd			
FuG right	0,6120 $\pm$ 0,0793	0,6098 $\pm$ 0,0523	0,031	0,913	0,913
FuG left	0,6348 $\pm$ 0,0549	0,6213 $\pm$ 0,0697	0,220	0,437	0,641
ITG right	1,0140 $\pm$ 0,1141	0,9330 $\pm$ 0,1073	0,728	0,012	0,091
ITG left	1,0079 $\pm$ 0,0965	0,9343 $\pm$ 0,0582	0,890	0,01	0,029
MTG right	1,1921 $\pm$ 0,1142	1,1255 $\pm$ 0,1029	0,607	0,020	0,110
MTG left	1,1443 $\pm$ 0,1302	1,0571 $\pm$ 0,0856	0,768	0,05	0,059
STG right	0,5720 $\pm$ 0,0698	0,5618 $\pm$ 0,0682	0,147	0,602	0,736
STG left	0,5422 $\pm$ 0,0670	0,5261 $\pm$ 0,0709	0,234	0,364	0,728
Occipital right	2,7508 $\pm$ 0,2592	2,6947 $\pm$ 0,1829	0,244	0,389	0,659
Occipital left	2,7357 $\pm$ 0,2286	2,7032 $\pm$ 0,1769	0,156	0,582	0,800
Calc right	0,2376 $\pm$ 0,0490	0,2453 $\pm$ 0,0557	-0,147	0,602	0,780
Calc left	0,2223 $\pm$ 0,0479	0,2452 $\pm$ 0,0502	-0,468	0,102	0,448
Cun right	0,3163 $\pm$ 0,0413	0,3116 $\pm$ 0,0253	0,130	0,644	0,746
Cun left	0,3197 $\pm$ 0,0352	0,3283 $\pm$ 0,0391	-0,234	0,236	0,649
LiG right	0,6577 $\pm$ 0,0721	0,6765 $\pm$ 0,0684	-0,266	0,348	0,767
LiG left	0,6527 $\pm$ 0,0583	0,6677 $\pm$ 0,0650	-0,245	0,387	0,709
IOG right	0,4532 $\pm$ 0,0758	0,4374 $\pm$ 0,0549	0,232	0,390	0,612
MOG total	0,8035 $\pm$ 0,1110	0,7636 $\pm$ 0,0766	0,407	0,154	0,564
MOG right	0,3916 $\pm$ 0,0618	0,3701 $\pm$ 0,0487	0,378	0,184	0,577
MOG left	0,4119 $\pm$ 0,0728	0,3935 $\pm$ 0,0521	0,284	0,317	0,774
SOG right	0,3017 $\pm$ 0,0444	0,3066 $\pm$ 0,0341	-0,121	0,668	0,735
SOG left	0,2745 $\pm$ 0,0381	0,2715 $\pm$ 0,0400	0,077	0,785	0,823

Table 2 Pearson correlation coefficients between left inferior Temporal gyrus (ITG left) volume and ocular biometric parameters

		Sferik R	Cxl R	AI-R	Acd-R	Sferik L	Cxl L	AI-L	Acd-L
ITG left	Pearson Correlation	-,404**	-0.106	,377**	,347*	-,405**	-0.075	,388**	,372**
	p	0.003	0.456	0.006	0.012	0.003	0.596	0.004	0.007

Values marked with one asterisk (*) indicate statistical significance at $p < 0.05$, while two asterisks (**) indicate statistical significance at $p < 0.01$. Sferik R / Sferik L: spherical equivalent refraction, right / left, Cxl R / Cxl L: corneal curvature (K value), right / left, AI-R / AI-L: axial Length, right / left, Acd-R / Acd-L: anterior chamber Depth, right / left, Itg left: left inferior Temporal gyrus volume

(p-values ranged between 0.000 and 0.026), with significance preserved after FDR correction. In particular, cortical thickness reductions were prominent in the right and left occipital lobes ($p = 0.001$, FDR_p = 0.002; $p < 0.001$, FDR_p = 0.002, respectively), Cal sulcus (right: $p < 0.001$, FDR_p = 0.002; left: $p < 0.001$, FDR_p < 0.001), Cun (right: $p = 0.001$, FDR_p = 0.004; left: $p < 0.001$, FDR_p < 0.001), and LiG (bilateral $p < 0.001$, FDR_p ≤ 0.001). Mild but significant reductions were also observed in the MOG and SOG bilaterally (e.g., MOG right $p = 0.005$, left $p = 0.009$; SOG right $p = 0.026$, left $p = 0.044$). No significant cortical thickness differences were found in temporal regions such as ITG, MTG, and STG (Table 3).

Analysis of correlations between cortical thickness norms of various brain regions and refractive parameters (spherical equivalent, refractive error, AL, and ACD) showed that FuG thickness correlated positively with spherical refractive values in both hemispheres (right FuG $r = 0.438$, $p = 0.001$; left FuG $r = 0.440$, $p = 0.001$). Conversely, AL and ACD were negatively correlated

with FuG thickness (e.g., right FuG and AL: $r = -0.472$, $p < 0.001$; left FuG and ACD: $r = -0.534$, $p < 0.001$). Similarly, occipital cortex thickness in both hemispheres showed positive correlations with spherical equivalent (right $r = 0.443$, $p = 0.001$; left $r = 0.466$, $p < 0.001$) and negative correlations with AL and ACD. Moreover, cortical thickness norms of the Cal sulcus, Cun, LiG, and MOG exhibited comparable patterns of positive correlations with spherical refractive values and negative correlations with AL and ACD (Table 4).

Discussion

In the present study, region-specific and directionally distinct alterations in brain morphometry were observed in patients with high myopia (HM). Importantly, these alterations differed in their robustness after correction for multiple comparisons. While volumetric increases were identified in temporal and association areas—particularly in the inferior and middle temporal gyri (ITG and MTG)—only the increase in the left ITG remained

Table 3 Cortical thickness measurements of selected brain regions are presented as mean $\pm$ standard deviation

Cortical Thickness of Selected Brain Regions	Myopia (n:30)	Healthy Control (n:22)	Cohen's d	p	FDR_p
	Mean $\pm$ Sd	Mean $\pm$ Sd			
FuG right thickness.	0,0338 $\pm$ 0,0025	0,0347 $\pm$ 0,0023	-0,363	0,201	0,403
FuG left thickness.	0,0335 $\pm$ 0,0022	0,0355 $\pm$ 0,0018	-1,027	0,001	0,002
ITG right thickness.	0,0338 $\pm$ 0,0023	0,0332 $\pm$ 0,0026	0,233	0,410	0,819
ITG left thickness.	0,0340 $\pm$ 0,0021	0,0335 $\pm$ 0,0023	0,237	0,403	0,806
MTG right thickness.	0,0301 $\pm$ 0,0027	0,0302 $\pm$ 0,0026	-0,015	0,958	1,915
MTG left thickness.	0,0307 $\pm$ 0,0025	0,0302 $\pm$ 0,0022	0,230	0,416	0,831
STG right thickness.	0,0242 $\pm$ 0,0030	0,0237 $\pm$ 0,0021	0,170	0,548	1,097
STG left thickness.	0,0251 $\pm$ 0,0028	0,0246 $\pm$ 0,0026	0,176	0,534	1,068
Occipital right thickness.	0,0210 $\pm$ 0,0023	0,0233 $\pm$ 0,0024	-1,010	0,001	0,002
Occipital left thickness.	0,0210 $\pm$ 0,0025	0,0236 $\pm$ 0,0021	-1,067	0,000	0,002
Calc right thickness.	0,0161 $\pm$ 0,0038	0,0202 $\pm$ 0,0039	-1,070	0,000	0,002
Calc left thickness.	0,0160 $\pm$ 0,0038	0,0216 $\pm$ 0,0031	-1,587	0,000	0,000
Cun right thickness.	0,0171 $\pm$ 0,0027	0,0195 $\pm$ 0,0024	-0,946	0,001	0,004
Cun left thickness.	0,0168 $\pm$ 0,0027	0,0200 $\pm$ 0,0024	-1,251	0,000	0,000
LiG right thickness.	0,0247 $\pm$ 0,0030	0,0281 $\pm$ 0,0029	-1,154	0,000	0,001
LiG left thickness.	0,0253 $\pm$ 0,0034	0,0288 $\pm$ 0,0026	-1,111	0,000	0,001
IOG right thickness.	0,0230 $\pm$ 0,0027	0,0241 $\pm$ 0,0031	-0,364	0,201	0,402
IOG left thickness.	0,0232 $\pm$ 0,0029	0,0237 $\pm$ 0,0032	-0,163	0,564	1,129
MOG right thickness.	0,0252 $\pm$ 0,0032	0,0278 $\pm$ 0,0028	-0,822	0,005	0,011
MOG left thickness.	0,0254 $\pm$ 0,0031	0,0277 $\pm$ 0,0030	-0,761	0,009	0,018
SOG right thickness.	0,0155 $\pm$ 0,0027	0,0174 $\pm$ 0,0032	-0,645	0,026	0,051
SOG left thickness.	0,0154 $\pm$ 0,0030	0,0172 $\pm$ 0,0030	-0,581	0,044	0,087

Cohen's d effect sizes are also provided. A p-value of <0.05 was considered statistically significant. FDR_p represents p-values corrected for multiple comparisons using the false discovery rate (FDR) method. Additionally, normalized cortical thickness results are included in the table, and all values are reported in millimeters (mm). FuG: fusiform gyrus, ITG: inferior Temporal gyrus, MTG: middle Temporal gyrus, STG: superior Temporal gyrus, calc: calcarine Cortex, cun: Cuneus, lig: lingual gyrus, IOG: inferior occipital gyrus, MOG: middle occipital gyrus, SOG: superior occipital gyrus

statistically significant following false discovery rate (FDR) correction. In contrast, cortical thickness reductions observed in the visual cortex and its subregions, including the fusiform gyrus (FuG), occipital lobe, calcarine sulcus, cuneus (Cun), lingual gyrus (LiG), middle occipital gyrus (MOG), and superior occipital gyrus (SOG), remained significant after FDR correction. This distinction suggests that cortical thinning in visual regions represents a more robust structural alteration in HM, whereas temporal volumetric increases should be interpreted more cautiously. Similar regional differences have been previously reported in the literature. Wu et al. documented significant cortical thinning in the occipital and lingual cortices in a HM cohort [13]. Huang and colleagues observed GM volume reductions in the right Cun and LiG alongside volumetric increases in certain limbic and temporal regions [7]. Our findings are in line with these observations, and the volumetric increases detected in temporal regions—particularly the ITG—may reflect compensatory reorganization related to sustained near-vision demands or altered visual experience in HM patients.

A large-sample UK Biobank study also reported structural differences in the temporal and parietal lobes of myopic individuals, along with volume changes

correlated with myopia severity [16]. This supports the notion that our observed volumetric increases may be linked to clinical severity. Moreover, animal model studies have demonstrated GM volume reductions in the visual cortex and associated regions, supporting the concept that myopia induces morphological changes not only at the retinal but also at the cortical level [17].

The volumetric increases observed in temporal regions have been interpreted within the framework of structural–functional reorganization in myopia [18], suggesting synaptic remodeling or compensatory expansion in response to altered visual input. Taken together, the coexistence of temporal volumetric increases and occipital cortical thinning observed in the present study underscores the complex and bidirectional nature of brain structural adaptations in HM.

Studies showing a decrease in occipital cortical thickness with reduced VA [19] are in agreement with the occipital thinning observed in our HM cohort. Additionally, reviews emphasizing central nervous system plasticity and the neuroanatomical consequences of visual experience [20] support the general framework of our findings.

Correlations between brain volumes and ocular parameters in our study particularly highlight significant

Table 4 Pearson correlation coefficients between normalized cortical thickness of selected brain regions and ocular biometric parameters

		SFERIK R	CXL R	AL-R	ACD-R	SFERIK L	CXL L	AL-L	ACD-L
FuG left thickness	Pearson Correlation	,438**	,376**	-,472**	-,522**	,440**	,349*	-,475**	-,534**
	p	0.001	0.006	0.000	0.000	0.001	0.011	0.000	0.000
Occipital right thickness	Pearson Correlation	,443**	,364**	-,447**	-,417**	,466**	,380**	-,464**	-,434**
	p	0.001	0.008	0.001	0.002	0.000	0.005	0.001	0.001
Occipital left thickness	Pearson Correlation	,465**	,316*	-,457**	-,447**	,485**	,313*	-,473**	-,469**
	p	0.001	0.023	0.001	0.001	0.000	0.024	0.000	0.000
Calc right thickness	Pearson Correlation	,454**	0.251	-,443**	-,423**	,478**	0.218	-,462**	-,452**
	p	0.001	0.073	0.001	0.002	0.000	0.120	0.001	0.001
Calc left thickness	Pearson Correlation	,626**	,319*	-,584**	-,557**	,643**	,317*	-,605**	-,581**
	p	0.000	0.021	0.000	0.000	0.000	0.022	0.000	0.000
Cun right thickness	Pearson Correlation	,393**	,365**	-,421**	-,371**	,437**	,331*	-,436**	-,395**
	p	0.004	0.008	0.002	0.007	0.001	0.017	0.001	0.004
Cun left thickness	Pearson Correlation	,502**	,387**	-,524**	-,451**	,539**	,419**	-,540**	-,460**
	p	0.000	0.005	0.000	0.001	0.000	0.002	0.000	0.001
LiG right thickness	Pearson Correlation	,489**	,328*	-,495**	-,444**	,505**	,303*	-,507**	-,461**
	p	0.000	0.018	0.000	0.001	0.000	0.029	0.000	0.001
LiG left thickness	Pearson Correlation	,477**	0.249	-,473**	-,460**	,499**	0.224	-,485**	-,486**
	p	0.000	0.075	0.000	0.001	0.000	0.111	0.000	0.000
MOG right thickness	Pearson Correlation	,360**	,388**	-,383**	-,355**	,375**	,442**	-,399**	-,362**
	p	0.009	0.005	0.005	0.010	0.006	0.001	0.003	0.008
MOG left thickness	Pearson Correlation	,344*	,294*	-,342*	-,363**	,353*	,292*	-,355**	-,384**
	p	0.013	0.035	0.013	0.008	0.010	0.036	0.010	0.005

SFERIK: spherical equivalent refractive error, CXL: corneal thickness, AL: axial length, ACD: anterior chamber depth; R: right eye, L: left eye. Values marked with one asterisk (*) indicate statistical significance at $p < 0.05$, and two asterisks (**) indicate significance at $p < 0.01$

associations between left ITG volume and spherical and axial ocular measurements. This suggests potential shared developmental or adaptive mechanisms linking ocular structure and brain morphology. However, given that only the left ITG volumetric increase remained significant after FDR correction, these associations should be interpreted cautiously.

For morphometric analysis, we employed VolBrain, an automated brain segmentation and volumetric measurement tool known for its high accuracy and user-friendliness [21]. VolBrain enables rapid volumetric assessment of various brain regions and is a reliable method preferred in clinical and research settings, especially with large datasets. Nevertheless, manual validation or cross-comparisons with alternative methods in smaller or disease-specific regions could enhance the reliability of findings. The applicability of VolBrain across different populations and disease groups is expanding, and it is considered a valuable tool for analyzing structural brain changes related to visual system disorders such as myopia [14, 22].

A primary limitation of this study lies in its relatively small sample size, which may limit the generalizability of the findings to broader populations. Moreover, the cross-sectional design restricts the ability to draw causal conclusions regarding the relationship between myopia and brain morphometric changes. The use of single

time-point measurements further constrains the evaluation of dynamic, longitudinal alterations. Additionally, the lack of functional data constitutes a significant limitation, preventing assessment of the functional implications or network-level effects of the observed structural changes.

Furthermore, although automated cortical segmentation methods enhance efficiency and reproducibility, their accuracy may be reduced in regions with high cortical curvature. Consequently, visual quality control remains essential to minimize potential segmentation errors and ensure the reliability of cortical morphometric measurements. In addition, the study cohort represents non-pathologic high myopia, as cases with degenerative fundus changes were excluded. Accordingly, the findings may not be generalizable to patients with pathologic or degenerative myopia. Future research employing longitudinal designs with larger sample sizes and integrating both structural and functional data is warranted to more comprehensively elucidate the association between brain morphology and myopia.

Conclusions

Overall, our findings indicate that myopia is associated with morphological differences not only at the ocular level but also in central nervous system structures. Future studies with larger samples and longitudinal designs that

incorporate both structural and functional measures are needed to clarify the causality and temporal progression of brain morphometric changes related to myopia.

Abbreviations

HM	High Myopia
MRI	Magnetic Resonance Imaging
GM	Gray Matter
WM	White Matter
VA	Visual Acuity
IOP	Intraocular Pressure
AL	Axial Length
ACD	Anterior Chamber Depth
FuG	Fusiform Gyrus
ITG	Inferior Temporal Gyrus
MTG	Middle Temporal Gyrus
STG	Superior Temporal Gyrus
Cal	Calcarine
Calc	Calcarine Cortex
Cun	Cuneus
LiG	Lingual Gyrus
IOG	Inferior Occipital Gyrus
MOG	Middle Occipital Gyrus
SOG	Superior Occipital Gyrus
BCVA	Best-Corrected Visual Acuity
HC	Healthy Control
MPRAGE	Magnetization Prepared Rapid Gradient Echo
TR	Repetition Time
TE	Echo Time
FDR	False Discovery Rate
AL-R	Right Eye Axial Length
AL-L	Left Eye Axial Length
ACD-R	Anterior Chamber Depth
ACD-L	Anterior Chamber Depth

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Author contributions

E.A contributed to the conception and design of the study and drafting the manuscript. Ö.P. performed volumetric analyses and contributed to data interpretation. Both authors read and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This observational and comparative study adhered to the principles of the Declaration of Helsinki and was approved by the Samsun University Non-Interventional Clinical Research Ethics Committee (Approval No. 2024/20/9).

Consent for publication

All authors have approved the manuscript for publication.

Competing interests

The authors declare no competing interests.

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